



***Computer Code, Data and
Evaluation Model (EM)
Verification & Validation (V&V)***

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August 22, 2005**

- **Issue Definition & Objective Outcomes**
- **Overall V&V strategy**
- **EM V&V approach and status**
- **Accident Analysis Process**
- **Software V&V approach and status**
- **Future V&V planning**
- **Next steps**
- **References**

- **Background**

- NRC analytical tool V&V issue as of 11/2001:
 - *How will analytical tools used to assess plant response to accident conditions be validated?*
- Exelon/PBMR response:
 - *Near term : V&V of various computer codes is to be done in stages; the initial strategy and plans will be available by mid-2002*
 - *Long Term: Computer code V & V activities will be ongoing over the next four years. A final version of the V&V plans ... will be available by April 2003*

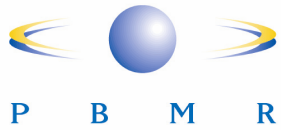
- **Current Issues**

- Confirmation of the suite of computer codes/evaluation models (EMs), the associated V&V process and related testing

- **The PBMR V&V process for EMs has been modified to closely follow NRC DG-1120**
 - e.g., EMDAP including PIRTs for normal operation, DBE, BDBE, etc.
- **Existing test data on TRISO fuel and data from existing/planned test facilities in SA are expected to fully support the safety related V&V process for the NRC in the US.**

- **Agreement on PBMR EM development and assessment process**
- **Agreement on the scope of the V&V computer code/EM suite**
- **Agreement on scope for the PBMR testing program for computer code/EM V&V**
- **Agreement on the planned white papers, topical reports, etc. and the DCA specification**

- **The Evaluation Model concept**
- **V&V approach**
- **Accident analysis process**

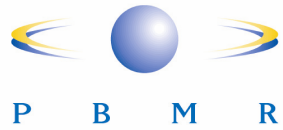


Overall V&V Strategy

The Evaluation Model concept:

Accident Analysis

**Calculation/analysis used to demonstrate that
Regulatory Acceptance Criteria are met for
defined licensing basis events.**



The Evaluation Model Concept

Evaluation Model

A calculational framework consisting of *one or more Calculation Models* and specific inputs used to model specific system behaviour under certain conditions.

The Evaluation Model Concept

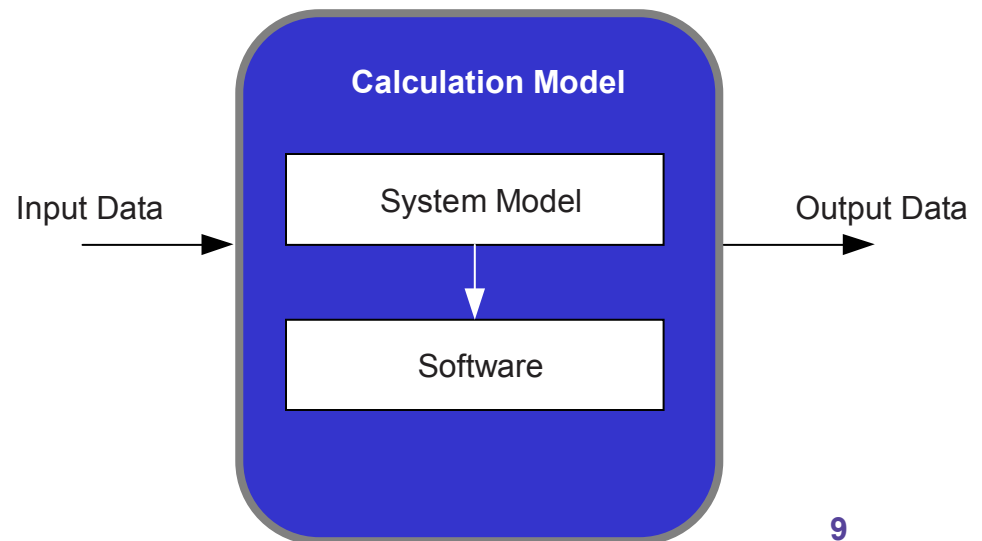
Calculation Model

An analytical quantification of a real system and the ways phenomena occur within that system, used to predict behaviour of the real system under specified conditions. Where a Software Product is used the Calculation Model is the combination of the *System Model* and *Software*.

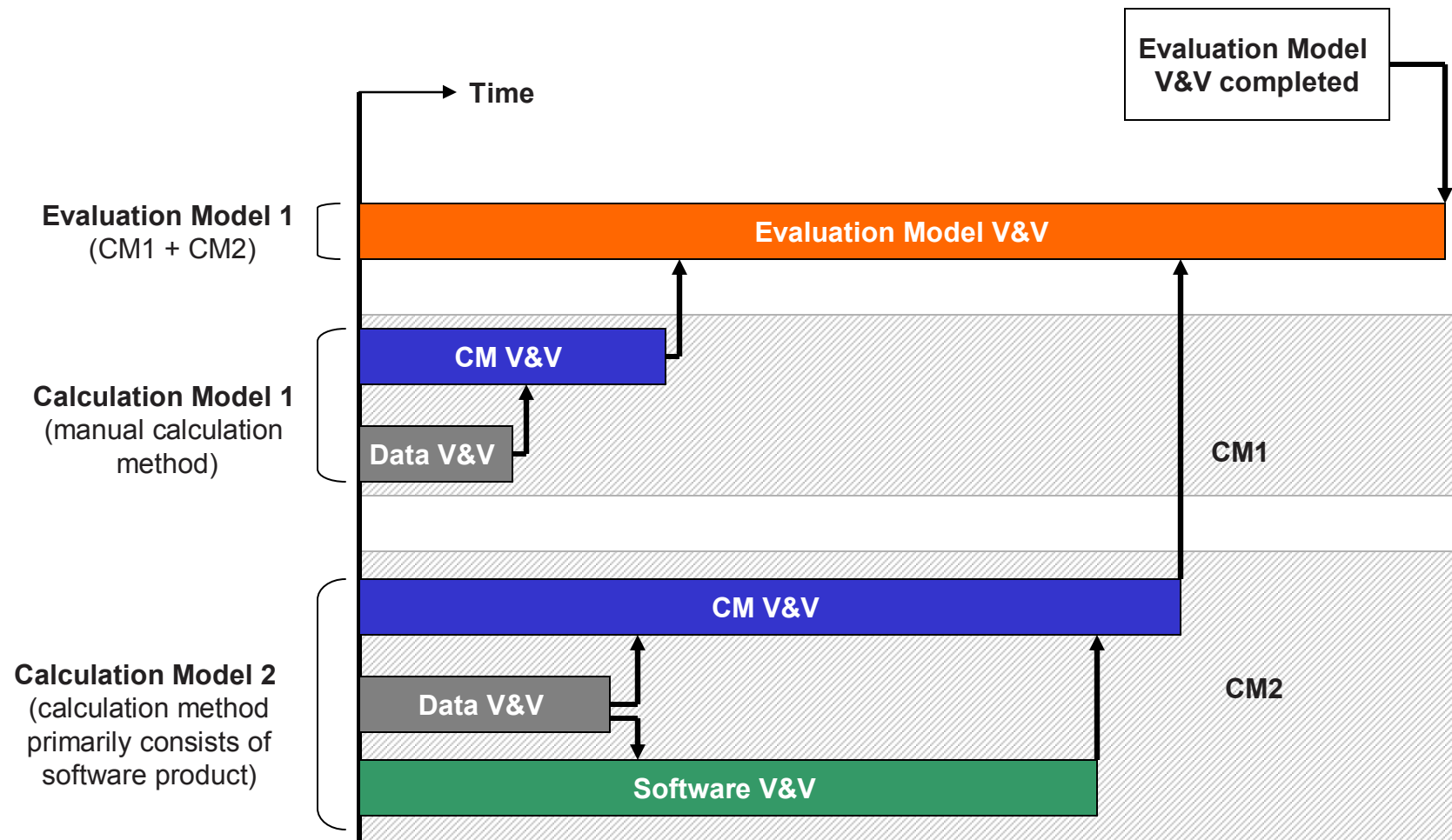
Manual Calculation Model:

$$x + y = z$$

or



Integrating the V&V Processes



Evaluation Models for PBMR Safety Analysis

Evaluation Model	Short Description	# Calc Models	Calculation Models Used
Pre-break	Calculates the expected pre-break conditions, just before a break in the Helium pressure boundary occurs. The time phase for this EM ends when such a break occurs. It does not include any of the phenomena that might occur during a pressure boundary break or later.	19	<ul style="list-style-type: none"> • VSOP99 PBMR400DP3 Reactor model • VSOP/CITATION 3D Model – RCS • VSOP/CITATION 3D Model – RSS • VSOP/CITATION 3D Model – RCS + RSS • MCNP 400MW PBMR Core & core structures model • SCALE Fuel Depletion Sources, Inventories and decay heat model • FLOWNEX MPS Model • CFD dust behaviour in MPS model • NOBLEG gaseous FP release model • FIPREX/GETTTER Metallic FP Release (normal geometry) model • RADAX PCU, FHSS, CCS, HICS, CBCS FP plate-out and dust distribution models • H3 Production model • C14 Production model • Turbine blade erosion productions model • Activation of erosion products model
Reactor cavity activation	Calculates the activation of Ar40 to Ar41 in the reactor cavity	2	<ul style="list-style-type: none"> • MCNP Reactor cavity interface radiation source model • Ar-41 Building release model
Heat removal transients	Calculates the transient reactor temperatures for forced cooling and loss of forced cooling scenarios.	2	<ul style="list-style-type: none"> • TINTE PBMR400DP3 Reactor model • FLOWNEX MPS Model
Reactivity transients	Calculates the transient reactor response for reactivity transient scenarios.	3	<ul style="list-style-type: none"> • VSOP99 PBMR400DP3 Reactor seismic model • TINTE PBMR400DP3 Reactor model • TINTE PBMR400DP3 Reactor seismic model
Air Ingress	Calculates the rate of air ingress for pipe break scenarios.	1 (+1 later)	<ul style="list-style-type: none"> • CFD Model for reactor air ingress • TINTE corrosion model – later

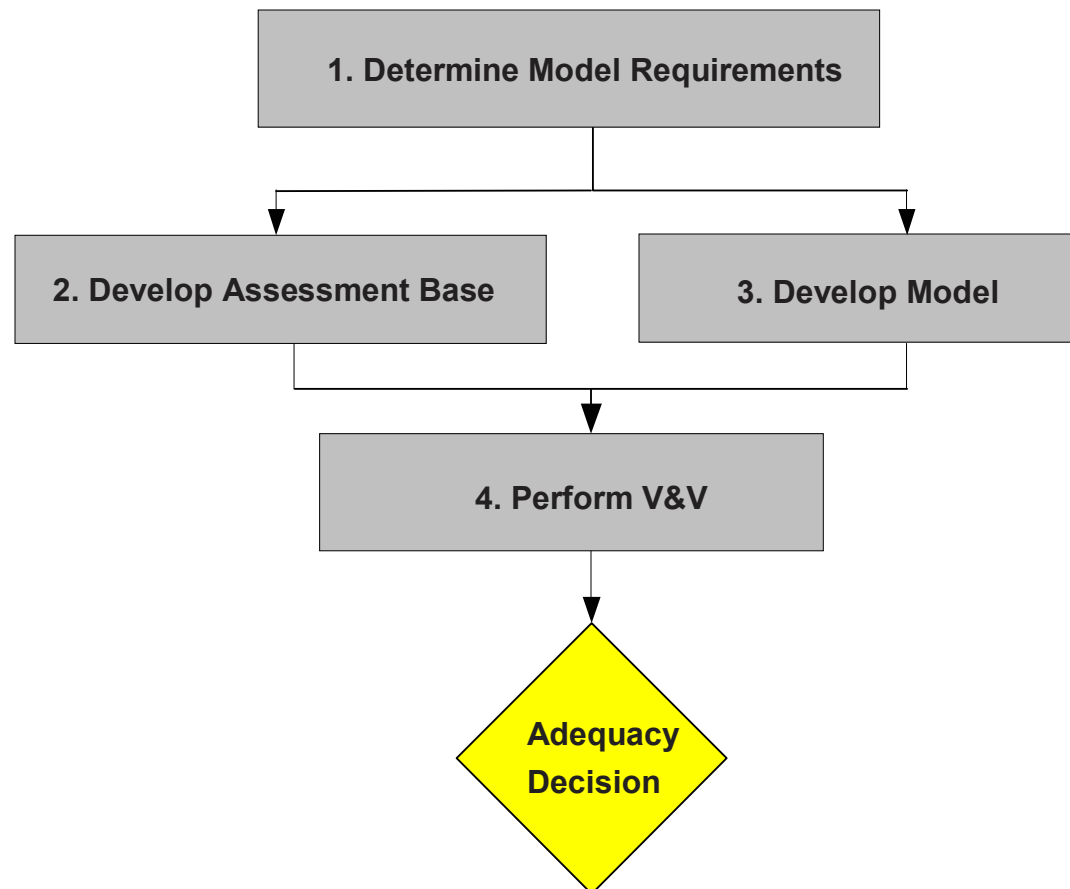


Evaluation Models for PBMR Safety Analysis

Evaluation Model	Short Description	# Calc Models	Calculation Models Used
Normal operation release	Calculates the release of activity during normal operation as a result of Helium Pressure Boundary leakage.	4	<ul style="list-style-type: none"> • AMBER Worker dose airborne activity from normal releases • AMBER Worker eDCF normal operations model • FLOWNEX MPS model • Waste characterization model
Atmospheric dispersion	Calculates the atmospheric dispersion and public dose	2	<ul style="list-style-type: none"> • PC-COSYMA Atmospheric dispersion model • ADMS Atmospheric Dispersion model
Initial Release	Release of activity already present in the circuit at the time of a break.	1	<ul style="list-style-type: none"> • FLOWNEX MPS Model
Initial Release worker dose	Calculates worker dose due to initial release.	1	<ul style="list-style-type: none"> • AMBER Worker eDCF initial release model
Delayed release worker dose	Calculates worker dose due to delayed release.	1	<ul style="list-style-type: none"> • AMBER Worker eDCF Delayed release model
Delayed release	Calculates the delayed release of fission products due to core heat-up for scenarios where there is a loss of forced cooling.	7	<ul style="list-style-type: none"> • VSOP99 PBMR400DP3 Reactor seismic model • TINTE PBMR400DP3 Reactor model • TINTE PBMR400DP3 Reactor seismic model • FIPREX/GETTTER Metallic FP Release (normal geometry) model • FIPREX/GETTTER Metallic FP Release (core compaction) model • Reactor unit retention model • Building retention model

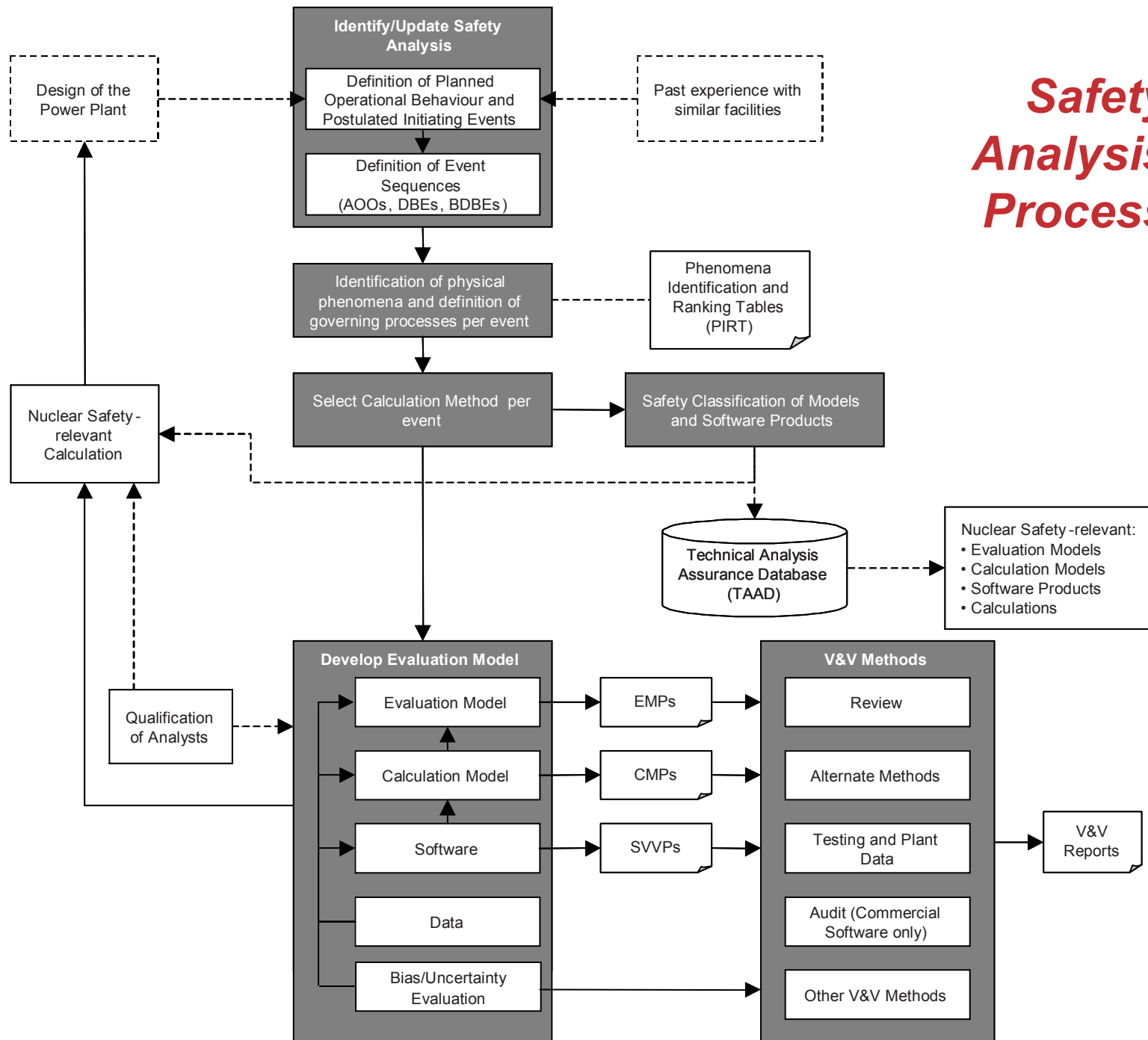
- Justify by one or more means that the calculation model integration passing outputs from one calculation model as inputs to the next calculation model is legitimate.
- Especially where the modeling of different effects is separated into more than one calculation model.
- If feedback effects or interdependencies exist the validity of separating them may well be jeopardized. In this case appropriate alternative models, experiments or plant data will need to be acquired to assess validity.

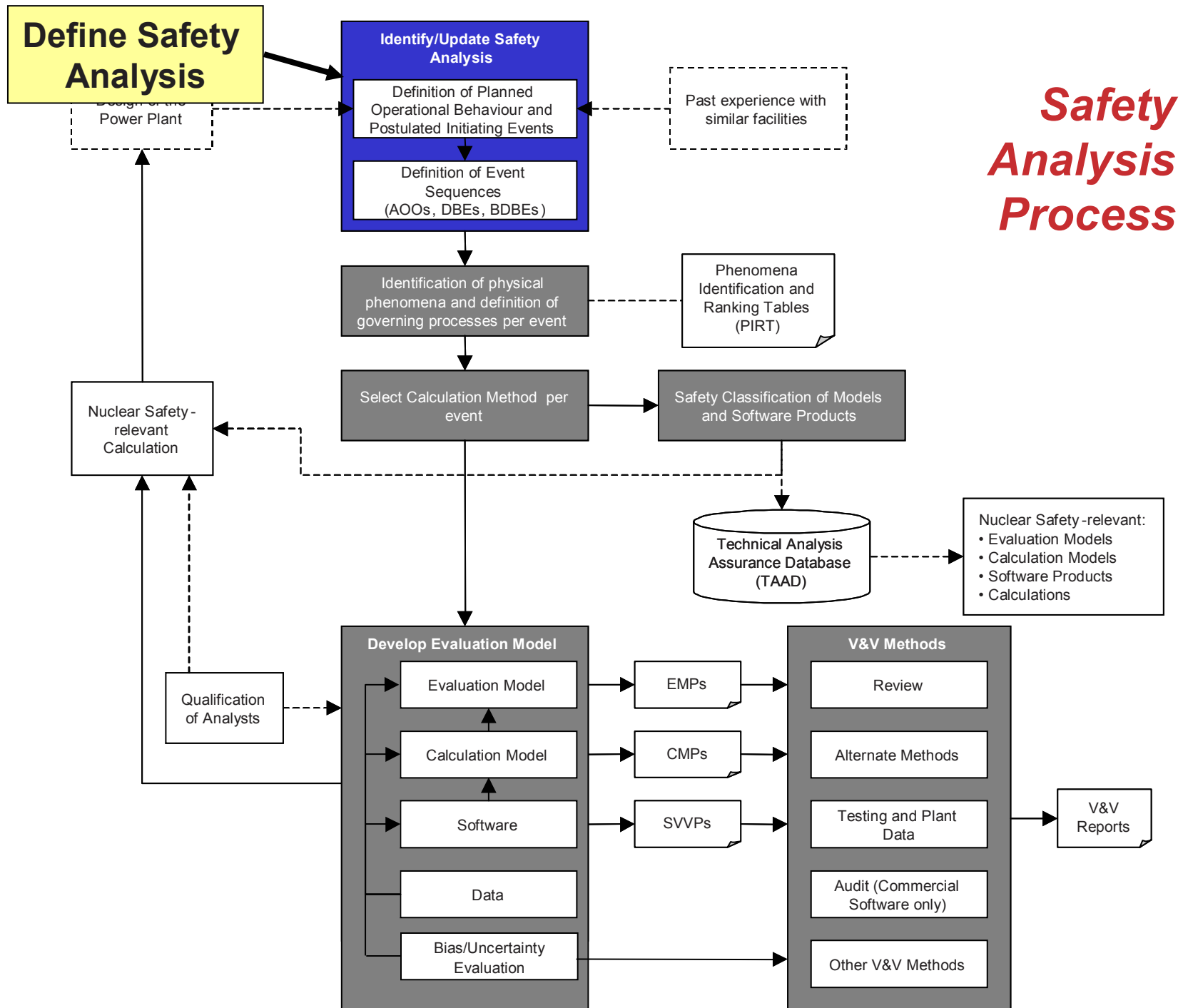
The EM development and V&V process applied at PBMR is based on NRC DG-1120.



- **PBMR plans to complete all evaluation model V&V planning by submission of the construction and installation safety case in March 2006.**
- **No feedback effects have been identified yet, thus the calculation model integration is justifiable in this fashion for the current licensing stage requirements.**

Safety Analysis Process





Safety Analysis Process

```

graph TD
    subgraph Design [Design of the Power Plant]
        DOPD[Design of the Power Plant]
    end
    subgraph PIRT [Perform Phenomena Identification and Ranking PIRT]
        PIRT_Box[Perform Phenomena Identification and Ranking PIRT]
    end
    subgraph IUSA [Identify/Update Safety Analysis]
        DPOBPE[Definition of Planned Operational Behaviour and Postulated Initiating Events]
        DES[Definition of Event Sequences AOOs, DBEs, BDBEs]
    end
    subgraph Phenomena [Phenomena Identification and Ranking Tables PIRT]
        PIRT_Table[Phenomena Identification and Ranking Tables PIRT]
    end
    subgraph SelectMethod [Select Calculation Method per event]
        SCME[Select Calculation Method per event]
    end
    subgraph SafetyClass [Safety Classification of Models and Software Products]
        SCMSWP[Safety Classification of Models and Software Products]
    end
    subgraph TAAD [(Technical Analysis Assurance Database TAAD)]
        TAAD[(Technical Analysis Assurance Database TAAD)]
    end
    subgraph NuclearSafetyCalc [Nuclear Safety-relevant Calculation]
        NSRC[Nuclear Safety-relevant Calculation]
    end
    subgraph QualAnalysts [Qualification of Analysts]
        QA[Qualification of Analysts]
    end
    subgraph DevelopEvalModel [Develop Evaluation Model]
        EM[Evaluation Model]
        CM[Calculation Model]
        SW[Software]
        DA[Data]
        BUE[Bias/Uncertainty Evaluation]
    end
    subgraph EMPs [EMP]
        EMPs[EMP]
    end
    subgraph CMPs [CMP]
        CMPs[CM]
    end
    subgraph SVVPs [SVVP]
        SVVPs[SVVP]
    end
    subgraph VVMethods [V&V Methods]
        Review[Review]
        AM[Alternate Methods]
        TPDT[Testing and Plant Data]
        ACS[Audit Commercial Software only]
        OVVM[Other V&V Methods]
    end
    subgraph VVReports [V&V Reports]
        VVR[V&V Reports]
    end

    DOPD -.-> DPOBPE
    PIRT_Box --> DPOBPE
    PIRT_Box --> DES
    PIRT_Box --> NSRC
    PIRT_Box --> SCME
    PIRT_Box --> QA
    PIRT_Box --> CM
    PIRT_Box --> BUE
    PIRT_Box --> EMPs
    PIRT_Box --> CMPs
    PIRT_Box --> SVVPs
    PIRT_Box --> Review
    PIRT_Box --> AM
    PIRT_Box --> TPDT
    PIRT_Box --> ACS
    PIRT_Box --> OVVM
    PIRT_Box --> VVR

    DPOBPE --> DES
    DES --> SCME
    SCME --> SCMSWP
    SCMSWP --> TAAD
    TAAD --> NSRC
    NSRC --> PIRT_Table
    PIRT_Table --> PIRT_Box
    QA --> EMPs
    QA --> CMPs
    QA --> SVVPs
    QA --> Review
    QA --> AM
    QA --> TPDT
    QA --> ACS
    QA --> OVVM
    QA --> VVR
    
```

The diagram illustrates the Safety Analysis Process, which is a systematic approach to identifying and ranking potential hazards and their consequences. The process begins with the **Design of the Power Plant**, which informs the **Identify/Update Safety Analysis** phase. This phase involves the **Definition of Planned Operational Behaviour and Postulated Initiating Events** and the **Definition of Event Sequences (AOOs, DBEs, BDBEs)**. The process then moves to the **Perform Phenomena Identification and Ranking (PIRT)** phase, which is a critical step in identifying and ranking potential hazards. This phase involves the **Identification of physical phenomena and definition of governing processes per event**, the **Select Calculation Method per event**, and the **Safety Classification of Models and Software Products**. The results of the PIRT phase are used to inform the **Technical Analysis Assurance Database (TAAD)**, which is a central repository for safety analysis data. The TAAD is then used to inform the **Nuclear Safety-relevant Calculation** phase, which involves the **Qualification of Analysts** and the **Develop Evaluation Model** phase. The **Develop Evaluation Model** phase involves the development of the **Evaluation Model**, the **Calculation Model**, the **Software**, the **Data**, and the **Bias/Uncertainty Evaluation**. The results of the **Develop Evaluation Model** phase are used to inform the **V&V Methods** phase, which involves the **Review**, **Alternate Methods**, **Testing and Plant Data**, **Audit (Commercial Software only)**, and **Other V&V Methods**. The final output of the process is the **V&V Reports**.

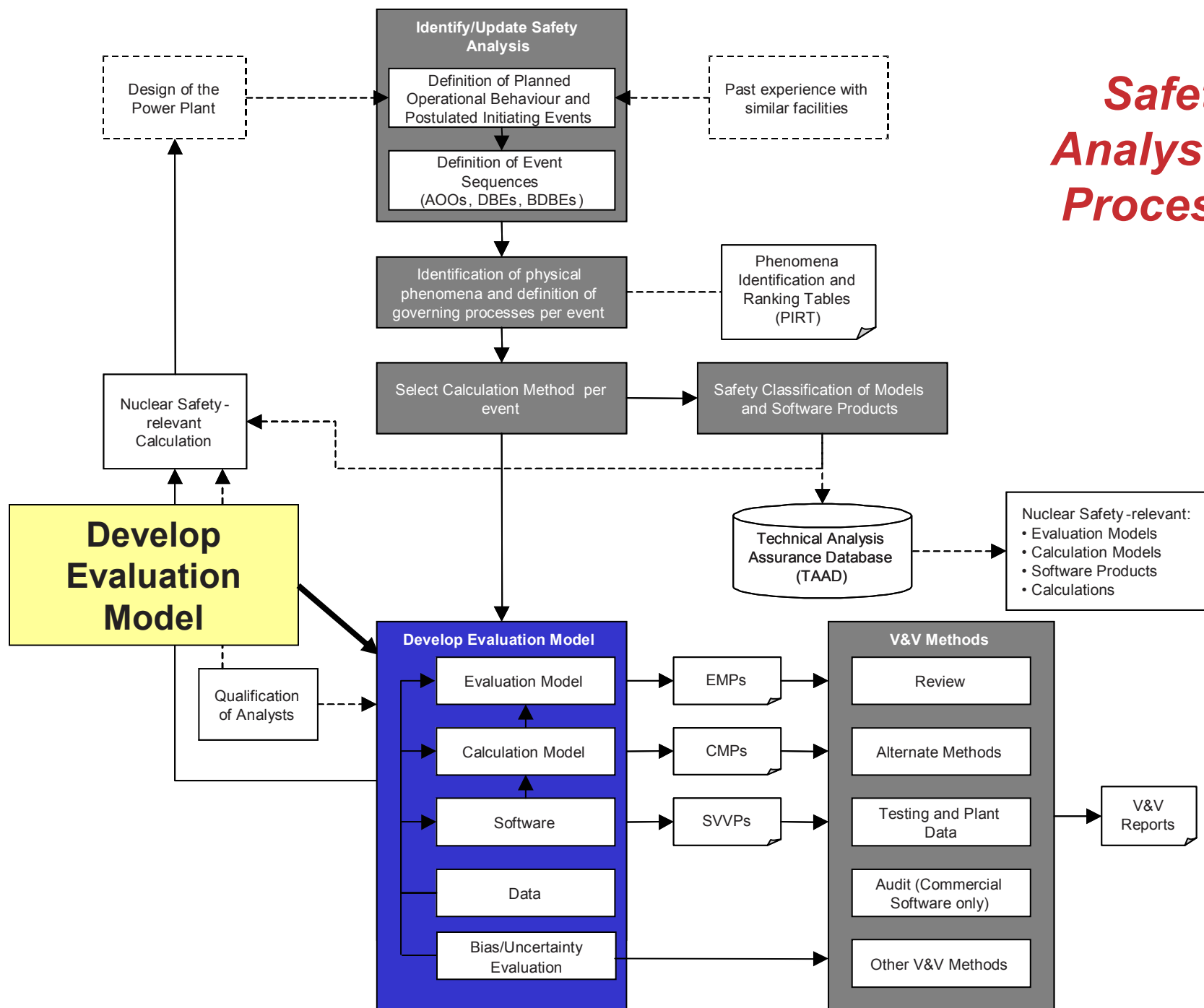
V&V Reports

- **PBMR has developed the following 13 PIRT tables:**
 - DLOFC, Delayed Release <10mm, unisolated break in PB
 - DLOFC, Delayed Release ≥10mm, unisolated break in PB
 - DLOFC, Delayed Release ≥16mm, unisolated break in HX
 - DLOFC, Initial Release <10mm, unisolated break in PB
 - DLOFC, Initial Release ≥10mm, unisolated break in PB
 - DLOFC, Initial Release ≥16mm, unisolated break in HX
 - Pressurized Loss of Forced Cooling
 - Air Ingress/Graphite Corrosion following break in He PB
 - Pre-break conditions, excluding PCU
 - Pre-break conditions, PCU
 - Atmospheric Dispersion of Radioactive Material
 - Reactor Cavity Activation
 - Citadel Building Retention

DLOFC = Depressurized Loss of Forced Cooling

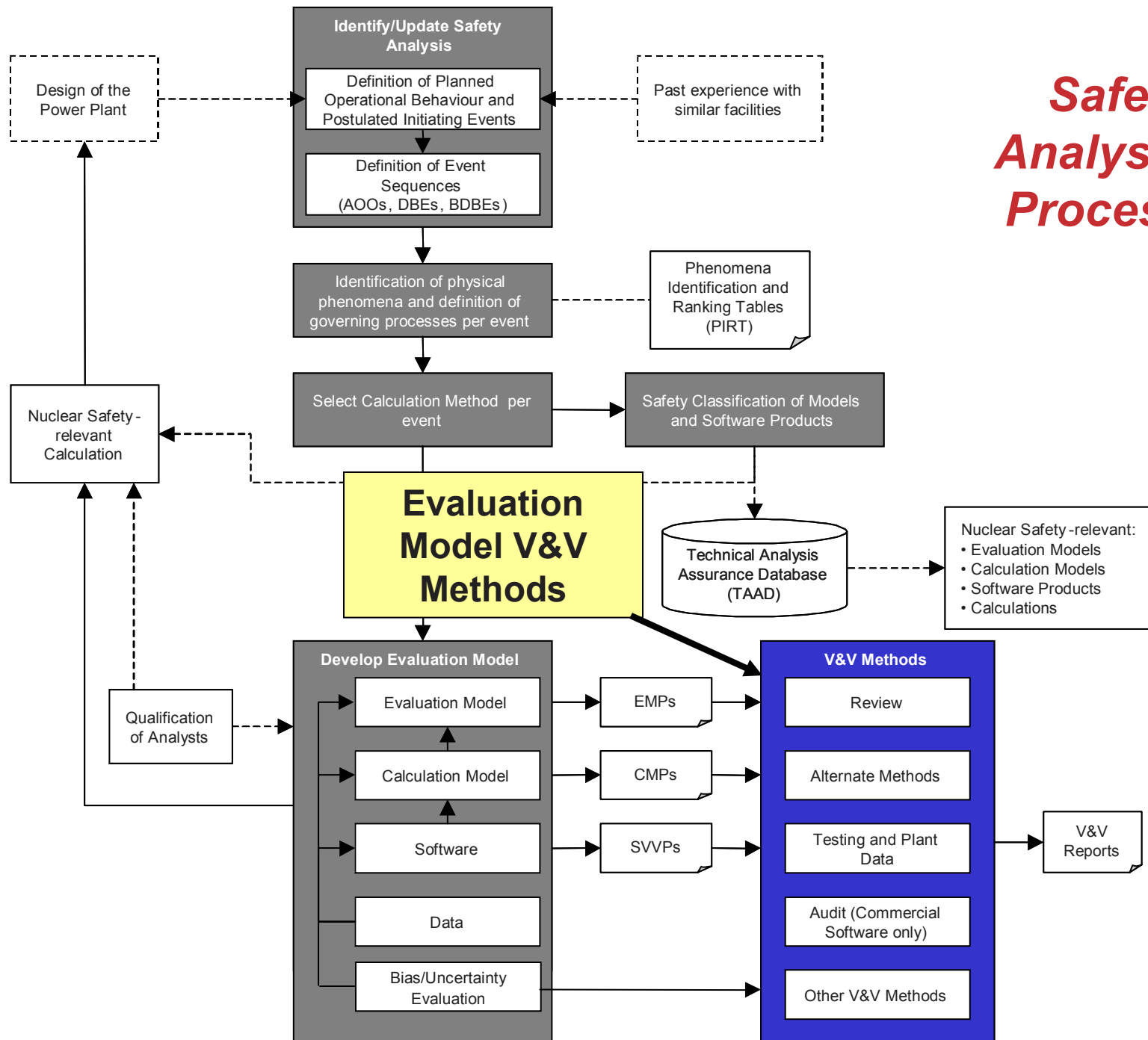
- **NRC TRISO PIRT**
 - Component (not event) oriented
 - Many phenomena covered by correlations (i.e., are not modeled in detail by PBMR)
- **INL VHTR PIRT**
 - High Pressure Conduction Cooling (HPCC)
 - Low Pressure Conduction Cooling (LPCC)
 - Load change full power to reduced power
- **ANL VHTR CSAU/PIRT**
 - Focused on DCC,PCC and Load Change

Safety Analysis Process

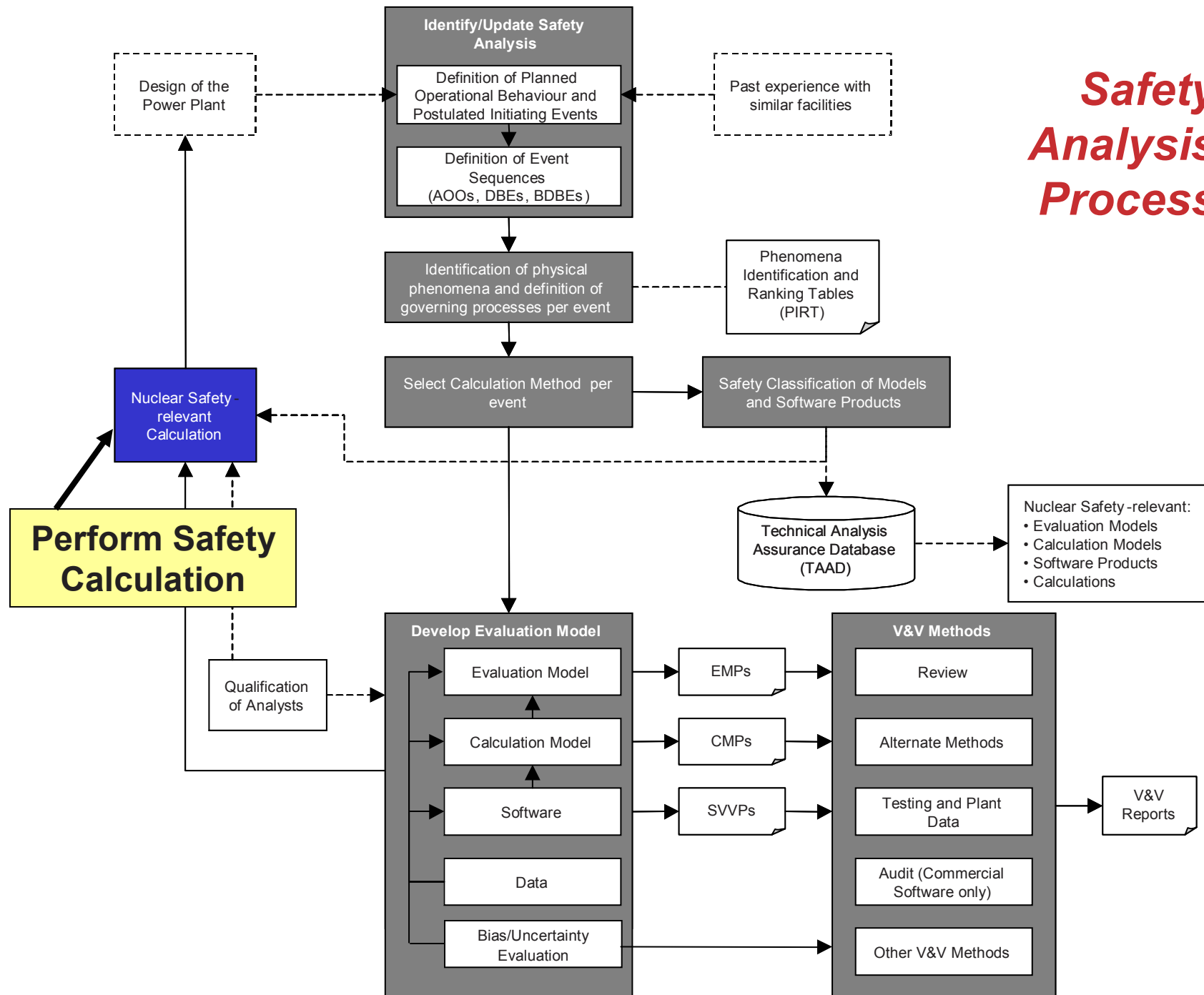


- **Evaluation Model Plans (EMPs), Calculation Model Plans (CMPs) and Software V&V Plans (SVVP) identify all V&V activities**
- **Planning for current and future V&V activities (for future licensing stage requirements)**

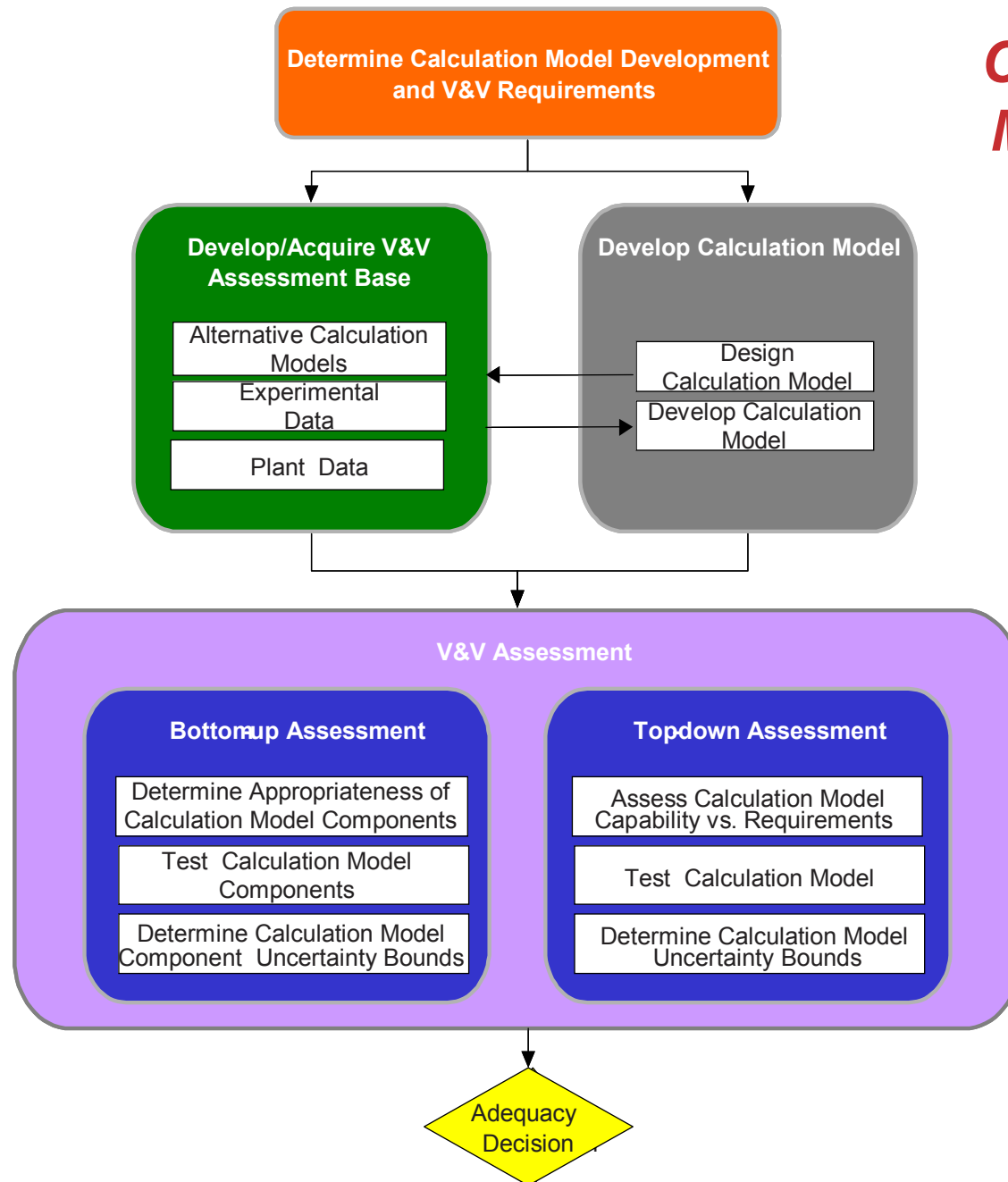
Safety Analysis Process

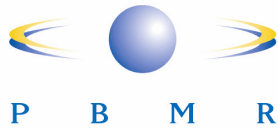


Safety Analysis Process



Calculation Model V&V Approach



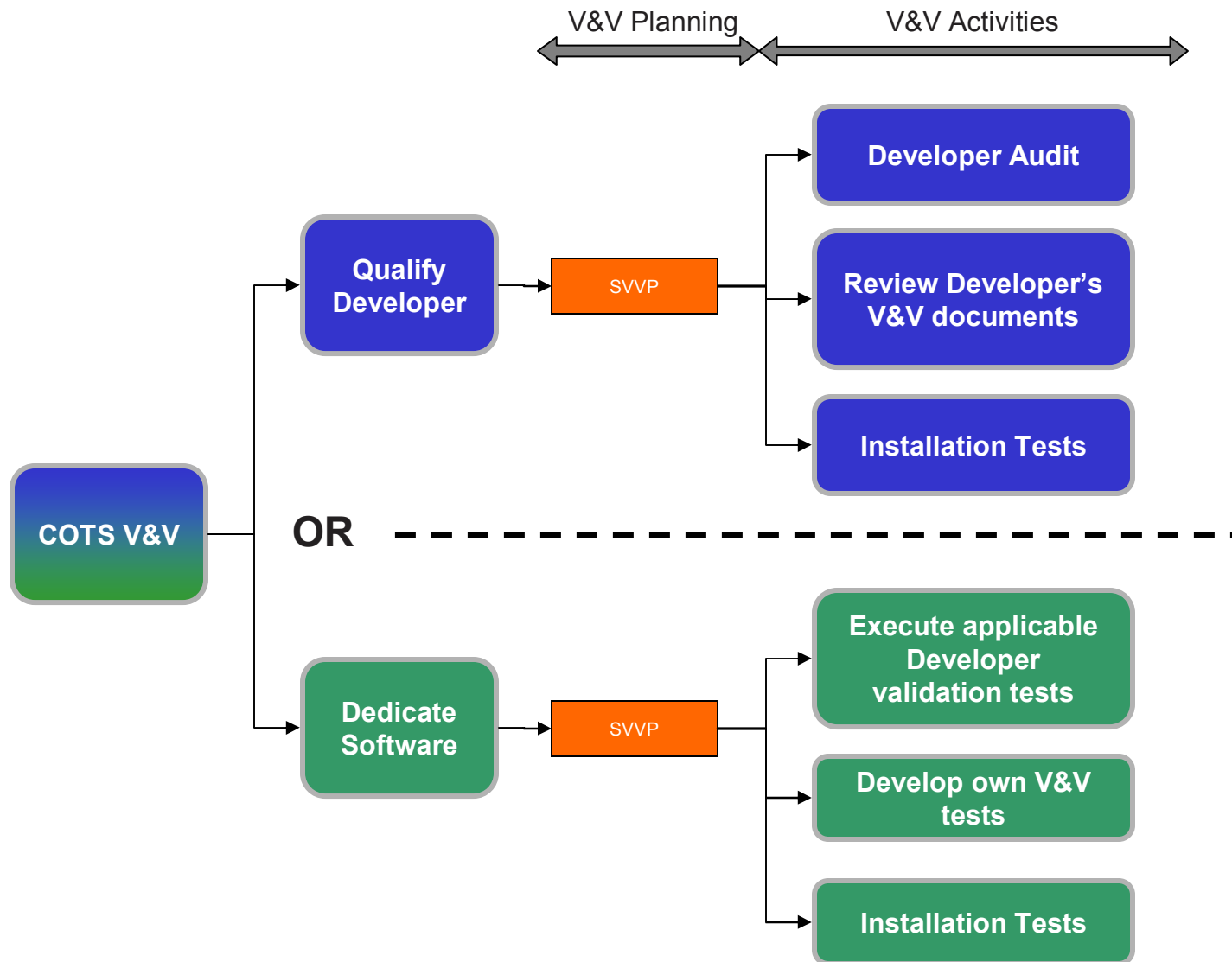


Calculation Model V&V Status

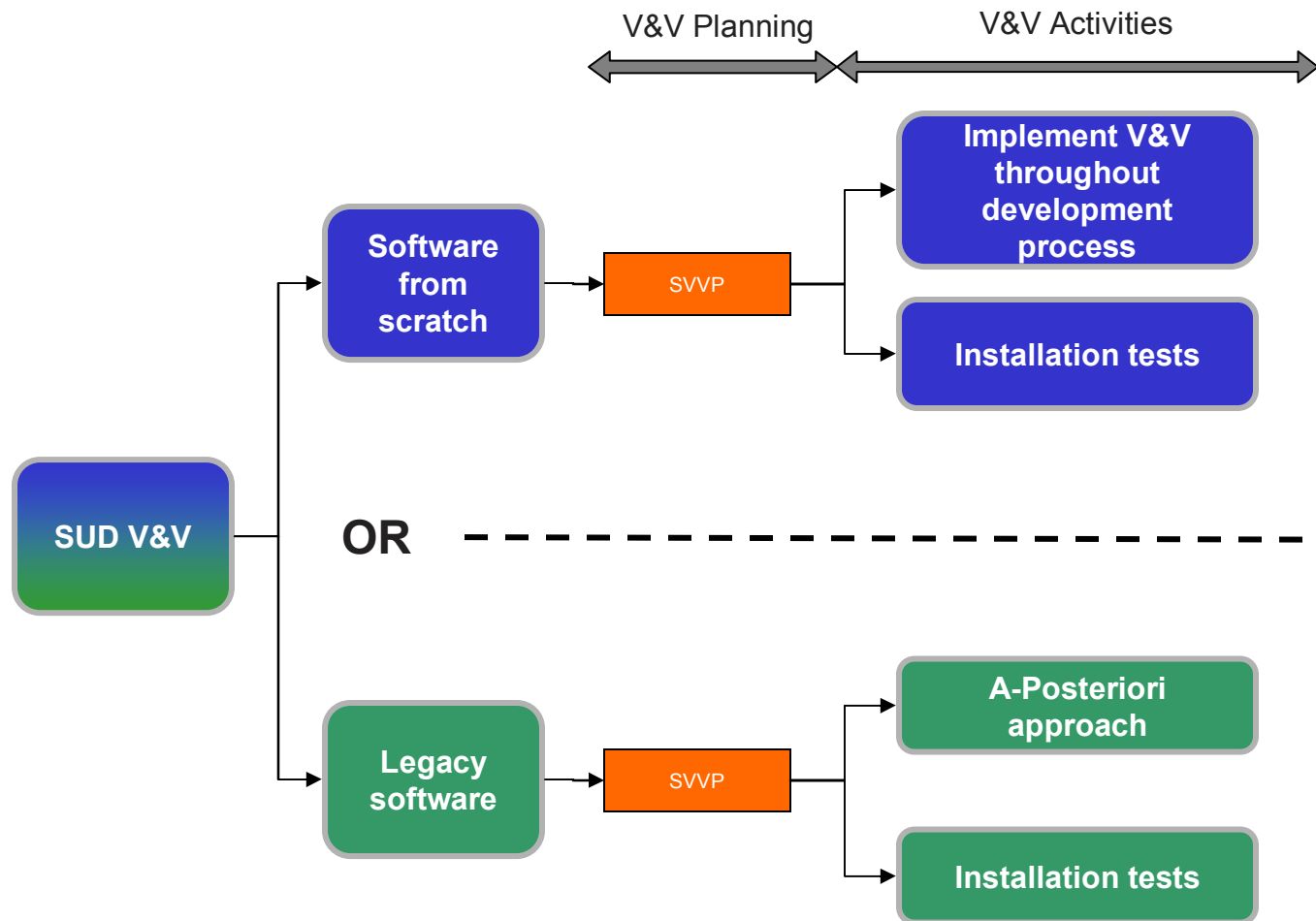
- **PBMR plans to complete all calculation model V&V planning by submission of the construction and installation safety case in March 2006.**
- **Alternative thermo-hydraulic cycle analysis comparisons have been performed.**
- **Alternative neutronic & thermo-hydraulic reactor analysis benchmarking in CRP-5**
- **Comparisons with Pebble Bed Micro-model Test Facility**
- **Pebble Bed Heat Transfer Test Facility detail design complete:**
 - High Pressure Test Unit (separate effects facility) operating by June 2006
 - High Temperature Test Unit (integral effects) operating by Dec 2006
- **Plate-out Test Facility basic design complete, should be operating by Dec 2006.**

- Different V&V approaches for the following types of software:
 - Commercial-Off-The-Shelf (COTS)
 - Software Under Development (SUD)
 - *Legacy*
 - *Software developed from scratch*

COTS V&V Approach



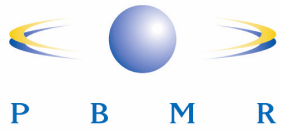
SUD V&V Approach



- **Commercial-Off-The-Shelf (COTS)**
- **Legacy Software Under Development**
- **Software developed from scratch**

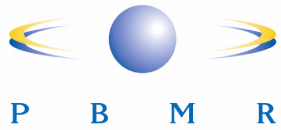
COTS Software V&V Status

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
MSC.Marc	Finite Element software for structural analysis	<u>Qualified Developer</u> <ul style="list-style-type: none"> • Developer audit • 17 installation tests 	<ul style="list-style-type: none"> • Installation tests complete • MSC audit completed • Dedication program to be initiated • V&V completion December 2005
MSC.Nastran	Finite Element software for structural analysis	<u>Qualified Developer</u> <ul style="list-style-type: none"> • Developer audit • 70 installation tests 	<ul style="list-style-type: none"> • Installation report complete • MSC audit completed • V&V completion October 2005



COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
PFC3D	For analyzing pebble bed flow, porosity and forces	<u>Dedication</u> <ul style="list-style-type: none"> • Installation tests • 6 validation tests 	<ul style="list-style-type: none"> • Installation report complete • Validation testing complete • V&V completed
SASSI	For earthquake induced seismic analysis	<u>Dedication</u> <ul style="list-style-type: none"> • Installation tests • 10 validation tests 	<ul style="list-style-type: none"> • Installation report complete • Validation testing complete • V&V completed

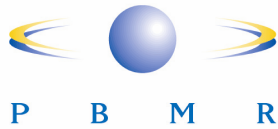


COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
RiskSpectrum	Fault and event tree analysis for PRA	<u>Qualified Developer</u> <ul style="list-style-type: none"> • Review developer V&V documents • 1 Installation test 	<ul style="list-style-type: none"> • V&V completed
PC Cosyma	Calculates dose and risk to public, using dispersion modeling	<u>Dedication</u> <ul style="list-style-type: none"> • 1 validation tests 	<ul style="list-style-type: none"> • V&V completed
LUDEP	Calculates worker dose due to inhalation	<u>Dedication</u> <ul style="list-style-type: none"> • 4 validation tests 	<ul style="list-style-type: none"> • V&V completed

COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
Fispact/ EASY	Calculates induced radioactivity of PCU and surroundings by neutrons from core	<u>Dedication</u> <ul style="list-style-type: none"> • 74 installation tests • Validation tests V&V of FISPACT-97	<ul style="list-style-type: none"> • V&V completed
Microshield	Calculates external dose rates to workers and shielding requirements	<u>Dedication</u> <ul style="list-style-type: none"> • Review developer V&V documents • 2 Installation tests 	<ul style="list-style-type: none"> • V&V completed
Fluent	CFD code for calculating fluid flow and heat transfer	<u>Dedication</u>	<ul style="list-style-type: none"> • V&V completed

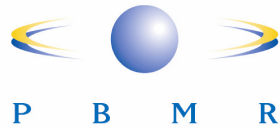


COTS Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
MCNP	Calculates radiation shielding and criticality	<u>Qualified Developer</u>	• V&V completed
AMBER	Calculates the migration and fate of contaminants in a system.	<u>Dedication</u>	• V&V completed
ADMS	Calculates the potential radiological dose to the public from a nuclear plant accident	<u>Dedication</u>	• V&V completed
Origen-Scale	Calculates time-dependent isotopic inventories in irradiated nuclear reactor fuel	<u>Qualified Developer</u>	• V&V completed

Legacy Software V&V Status

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
VSOP99	Suite of interlinked codes calculating reactor operational history and quasi-steady state reactor core neutronic analysis	<u>Posteriori V&V</u> Joint effort between PBMR and FZJ	<ul style="list-style-type: none"> • SVVP complete • Posteriori V&V baseline established by Nov '05 • Re-engineering of development products to be carried out from 2006
Radax	Determines fission product concentration and dust distribution throughout the MPS	<u>Posteriori V&V</u> Joint effort between PBMR and Westinghouse Reaktor (GmbH)	<ul style="list-style-type: none"> • SVVP completed by Dec '05



Legacy Software V&V Status (Cont'd)

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
TINTE	Simulates transient behaviour of the reactor core	<u>Posteriori V&V</u> Joint effort between PBMR and FZJ	<ul style="list-style-type: none"> • SVVP complete • Posteriori V&V baseline established by Nov '05 • Re-engineering of development products to be carried out from 2006
GETTER	Calculates the time dependent release of long-lived metallic fission products from the spheres	<u>Posteriori V&V</u>	<ul style="list-style-type: none"> • SVVP completed by Dec '05
NobleG	Calculates the steady state release of noble gases (Kr, Xe) and the halogens (Br, I) from the fuel spheres	<u>Posteriori V&V</u>	<ul style="list-style-type: none"> • Phase 1 completed (initial validation and theory verification, SVVP, Baseline V&V Status Report, and V&V Measures Test Plan)

Developed Software V&V Status

Software Products	Description and Use	V&V Approach	Progress, Key Milestones
FIPREX	Pre- and post processor for GETTER input and output	<u>Development V&V</u>	<ul style="list-style-type: none"> • Verification completed by Dec '05 • Validation completed by Dec '06
Flownex	An implicit thermal-fluid network analysis code used for the analysis of temperatures, pressures and mass flows	<u>Development V&V</u>	<ul style="list-style-type: none"> • V&V completed

- **Evaluation Model V&V**
- **Calculation Model V&V**
- **Data V&V**

The V&V approach: to justify that the software product integration is legitimate (especially where the modeling of different effects is separated into one or more software products)

- This will be determined by a line-by-line review of the evaluation model.
- If feedback effects are found, a comprehensive V&V effort is required against an assessment base.
- No feedback effects have yet been identified, thus the model integration is justifiable using this approach for the current licensing stage requirements.

The V&V approach: a comprehensive V&V effort using an appropriate assessment base

- **Performing a bottom-up assessment of the Calculation Model components**
- **Performing a top-down assessment of the integrated Calculation Model**
- **All of the Calculation Model Plans (CMPs) will be completed during Design Certification.**

The data used in Calculation Models (System Models), Calculations and Software Products (embedded data) shall be strictly controlled and under change management.

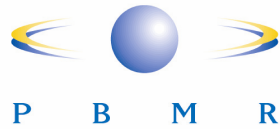
- **Each item of data shall have a clearly defined origin in documentation, technical databases, or its source shall be clearly identified.**
- **All un-validated data shall be identified as an outstanding item.**
- **Data V&V activities shall be planned in the V&V register and managed to completion.**

Area of Review	Timing	Pre-application Work Item(s)
Analytical Codes and Software Control		
PANAMA		PANAMA has been replaced by spreadsheet calculations.
RAIs 5.1.1-5.1.5	1	
FRESCO		FRESCO has been replaced by GETTER.
RAIs 5.1.6, 5.1.7	1	
PANAMA and FRESCO		
RAIs 5.1.8, 5.1.9	1	
RAIs 5.2.1-5.2.3	2	
General Issues		
RAIs 5.2.4-5.2.8	2	

Area of Review	Timing	Pre-application Work Item(s)
Core Design and Heat Removal		
RAIs 6.2.1*-6.2.6*, 6.2.8*, 6.2.10*, 6.2.19*, 6.2.20*, 6.2.22*-6.2.26*, 6.2.28*- 6.2.32*, 6.2.37*, 6.2.55	2	
PBMR Operational Modes and States		
RAI 7.1.2	1	
RAI 7.2.1	2	

General Steps of Work

- Identify documentation required by the NRC for pre-licensing review of computer code/EM V&V methodology
- Compare PIRTs generated by PBMR with other VHTR PIRTs (when they become available)
- Document relationship of PBMR testing program to the computer code/EM V&V process
- Workshop(s)
- RAI's from NRC
- RAI Response Workshop and draft DCA spec for topic
- Revised Final Papers and DCA specification
- NRC closure documentation



Background References

- **“Summary of Pre-application Presentations Regarding the Pebble Bed Modular Reactor (PBMR),” Exelon letter from K. F. Burton to U.S. Nuclear Regulatory Commission, Project No. 713, dated October 30, 2001.**
- **“Response to NRC Letter dated September 26, 2001 Regarding the Pebble Bed Modular Reactor Technical Information Availability,” Exelon letter from K. F. Burton to U.S. Nuclear Regulatory Commission, Project No. 713, dated November 15, 2001.**
- **“Request for Additional Information (RAI) on Analytical Codes and Software Control; Core Design and Heat Removal and; Operational Modes and States for the Pebble Bed Modular Reactor (PBMR),” NRC letter from F. Eltawila to K. Borton, May 31, 2002.**